

Habitat Modeling and Preferences of Marine Mammals as Function of Oceanographic Characteristics: Development of Predictive Tools for Assessing the Risks and the Impacts Due to Sound Emissions

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LONG-TERM GOALS

Long-term goals of this research are:

- Improving the knowledge about marine mammal ecology and about how ocean dynamics affect their distribution and behavior in different areas;
- Developing the tools enabling to predict marine mammal presence probability or density on the basis of the data available to detect their presence (i.e. visual observations or acoustic detections) and the available environmental predictors;
- Creating the knowledge-based background about potential mitigation measures appropriate for different areas;
- Creating a Decision Support System of Rules that will constitute a guideline for choosing the appropriate combination of the tools at managers' disposal which is likely to be the best way to maximize effective mitigation efforts.

OBJECTIVES

Three are the main scientific objectives of this research:

- Objective 1) Development of methods to integrate acoustic and visual data in marine mammal distribution/density models;
- Objective 2) Evaluation of the model transferability to areas different from the zone of calibration;
- Objective 3) Definition of a knowledge-based decision support framework for managing the impact of the noise-producing human activities.

APPROACH

The graph in Figure 1 outlines the set of tasks composing the Objectives of the research for the development of the risk assessment models. The technical approach for every Objective is discussed in the following paragraphs.

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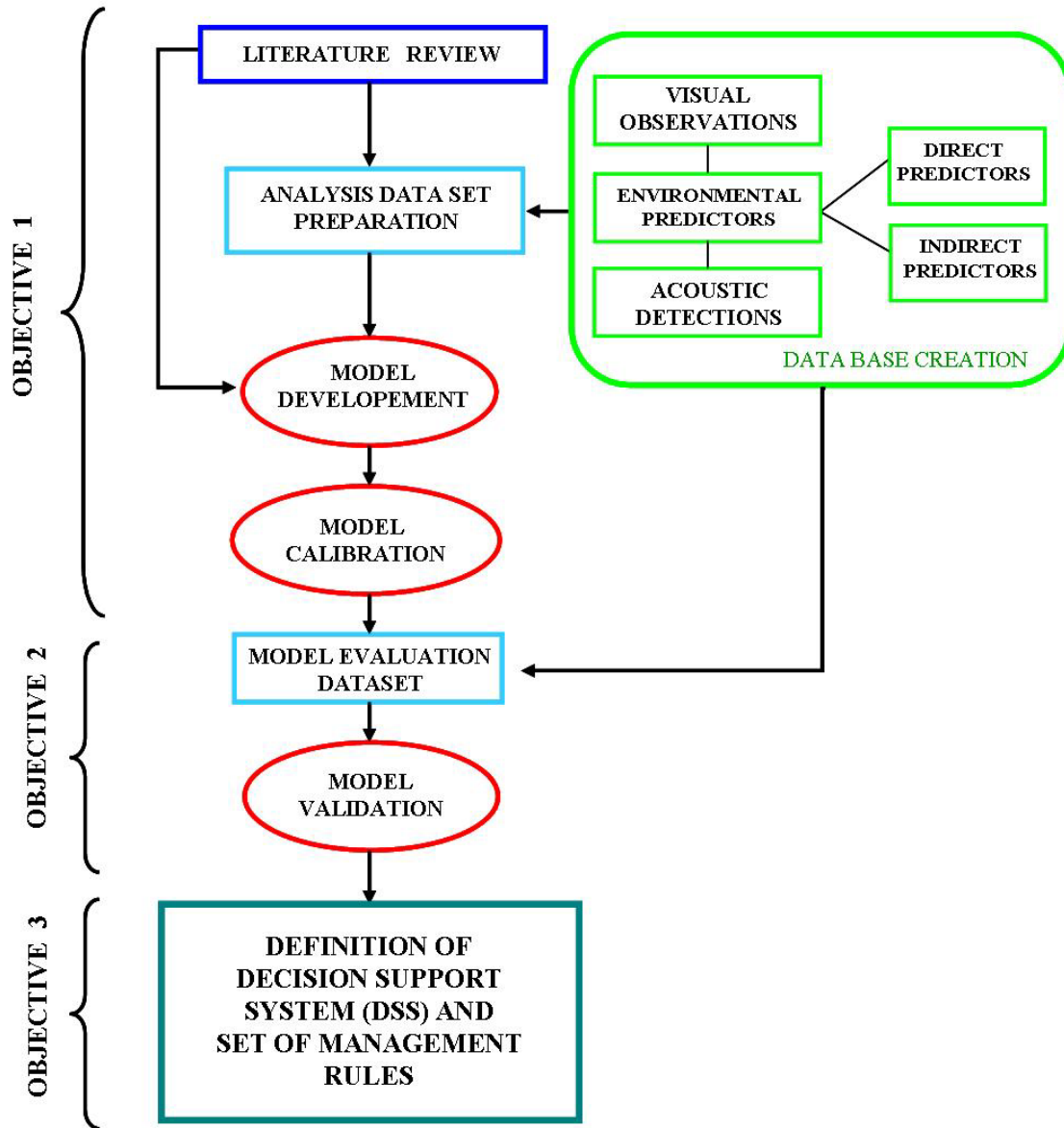


Figure 1. Risk Assessment Models Development Process.

Research tasks (boxes) included in every research Objective.: **Literature review:** critical review of different statistical methodology , response variables and predictors availability; **Database creation:** data acquiring of the sightings, passive acoustic detections and indirect (mainly physiographical parameters such as depth, slope) and direct (data from CTD probes such as temperature, salinity; data from remote sensing such as Chl-a) predictors; **Analysis datasets:** preparation of dataset for developing and running different model exercises (calibration/validation models); **Modeling:** calibration, best model selection, validation, scenario analysis; **Decision Support System:** guideline framework for choosing the appropriate set of risk mitigation alternatives.

Objective 1:

Modeling exercises will be run for determining regions of high and low marine mammal presence/density through the analysis of the literature available, the oceanographic, biological and historical information available on the Mediterranean and the Antarctic study area. Different statistical approaches (e.g. Logistic regressions, Generalized Linear Models) will be used to model density and presence/absence patterns of target species. A consolidate methodology will be developed to integrate acoustic and visual data in marine mammal distribution models.

Objective 2:

The transferability of the developed models to areas different from the zone of calibration, and the assessment of behavioral differences of the same species inhabiting different areas will be evaluate by using different environmental parameters such as indirect (depth, slope..) and direct (temperature, salinity..) ecological gradients. The analysis of model results of the same species in different areas (e.g. Ligurian sea, Alboran sea) allow to outline behavioral differences that may affect their distribution pattern and response to environmental predictors.

Objective 3:

The components of systems for managing the effects of sound on marine mammals include knowledge and research, risk assessment, permit and authorization processes, mitigation tools and monitoring, evaluation, enforcement, and compliance activities. Mitigation may consist of different alternatives that could be more or less appropriate from case to case. The choice among different mitigation alternatives designed to prevent, reduce or rectify the impacts of sound introduced into the marine environment may be guided through a set of rules, based on risk predictions, organized into a decisional framework which will also include the suite of tools needed to support decisions.

Key individuals of the research are.

Arianna Azzellino, PhD: Principal Investigator (PI)

Caterina Lanfredi: Phd student (PS)

Roles played by principal investigator (PI) and the PhD student (PS):

PS	Literature review
PI+PS	Data acquiring and database creation
PS	Analysis data set preparation
PI+PS	Modeling (calibration, best model selection, validation, scenario analysis)
PI+PS	DSS system creation when used in areas different from the calibration site.

WORK COMPLETED

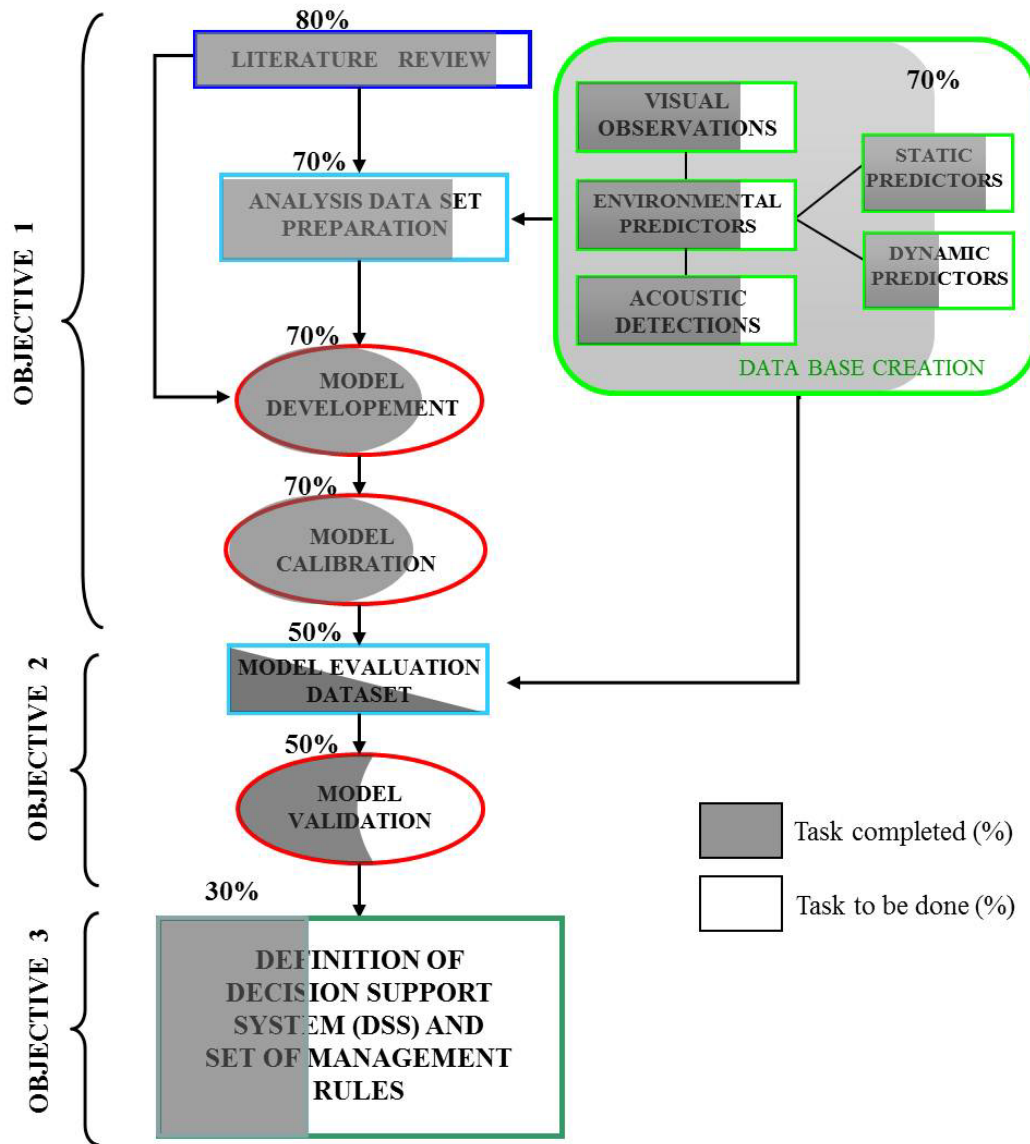


Figure 2. Risk Assessment Models Development Process.

RESULTS

Modeling exercises were run for different areas of the Mediterranean sea combining visual observations, passive acoustic detections and oceanographic data (CTD) coming from NURC/Sirena and MED09 surveys conducted in the Ligurian Sea, Alboran Sea and Tyrrhenian Sea.

Modeling concerned two different analysis:

1. the correlation between Cuvier's beaked whale occurrence and oceanographic parameters, that was analyzed in three key areas in the Mediterranean Sea.
2. The comparison of the results obtained from acoustic-based and visual-based models;

1. Correlation between Cuvier's beaked whale occurrence and oceanographic parameters:

Target species of the first modeling exercise was the Cuvier's beaked whale (*Ziphius cavirostris*). The correlation between Cuvier's beaked whale presence/absence and oceanographic parameters was analyzed for three key areas of the Mediterranean Sea: the Genoa canyon area in the Ligurian Sea, the waters surrounding Alboran island in the Alboran Sea, and the Northwestern Tyrrhenian Sea (Fig.3). Visual observations, acoustic detections and concurrent oceanographic data collected during the MED09 sea trial (Fig.4), during the Sirena 2002, and 2008 cruises (Fig.5a. and 5b.) were analyzed. Temperature, salinity, sound velocity, dissolved oxygen, fluorescence and turbidity were measured as a function of depth using sensors installed on a CTD (Conductivity, Temperature, Depth) Rosette Frame deployed at predefined points, called stations, from the NATO Research Vessel Alliance. 39 water column statistics were computed for every oceanographic parameter collected in every station. These statistics were used as covariates in the models. Details of the analysis dataset are presented in Table 1 and Figure 6.

Table 1. Analysis database used for the modeling exercises.

Areas	Ligurian Sea	Alboran Sea	Tyrrhenian Sea
Research Trials	<i>Sirena '02</i>	<i>Sirena '08</i>	<i>Med '09</i>
Time period	<i>5 - 23 July</i>	<i>17 May - 18 June</i>	<i>29 August - 4 September</i>
Research Vessel	<i>NRV Alliance</i>	<i>NRV Alliance</i>	<i>NRV Alliance</i>
CTD stations	21	31	5
BW sightings	24	6	6
BW acoustic detections		5	9

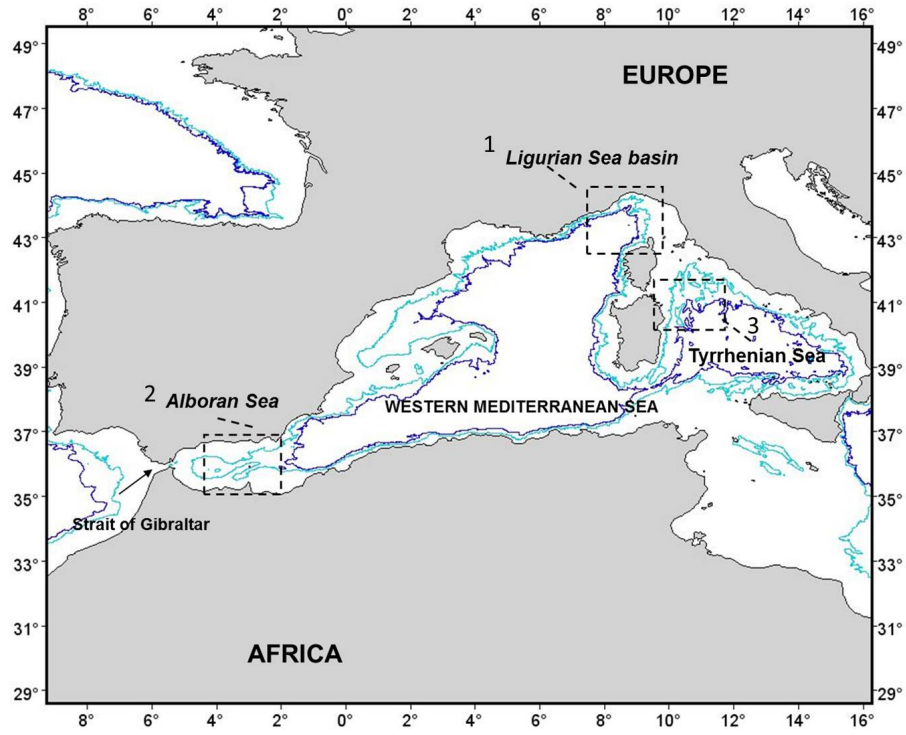


Figure 3. Mediterranean Sea study areas: 1. Northwestern Mediterranean Sea (Ligurian Sea Basin) and 2. Southwestern Mediterranean Sea (Alboran Sea) and 3. Central Mediterranean Sea (Tyrrhenian Sea). 1000 m (light blue lines) and 2000 m (blue lines) depth contours are shown.

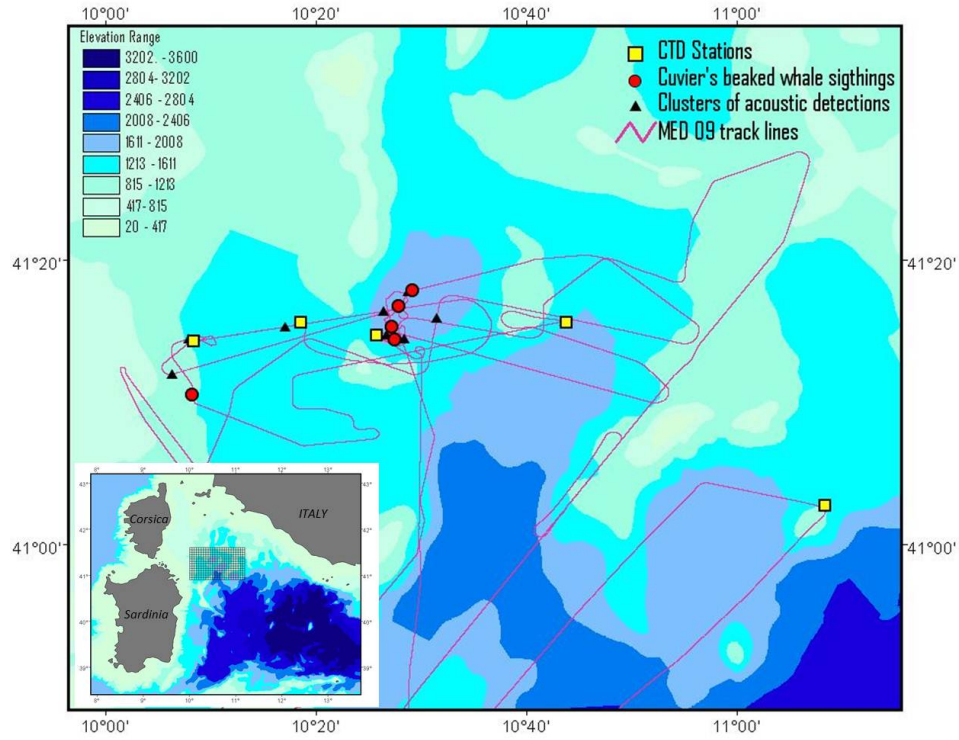


Figure 4. MED09 lag3 study area (Northwestern Tyrrhenian Sea). Beaked whale sightings (red circles) passive acoustic detections (black triangles) and CTD stations (yellow squares) are shown. Ship track lines are also shown.

a)

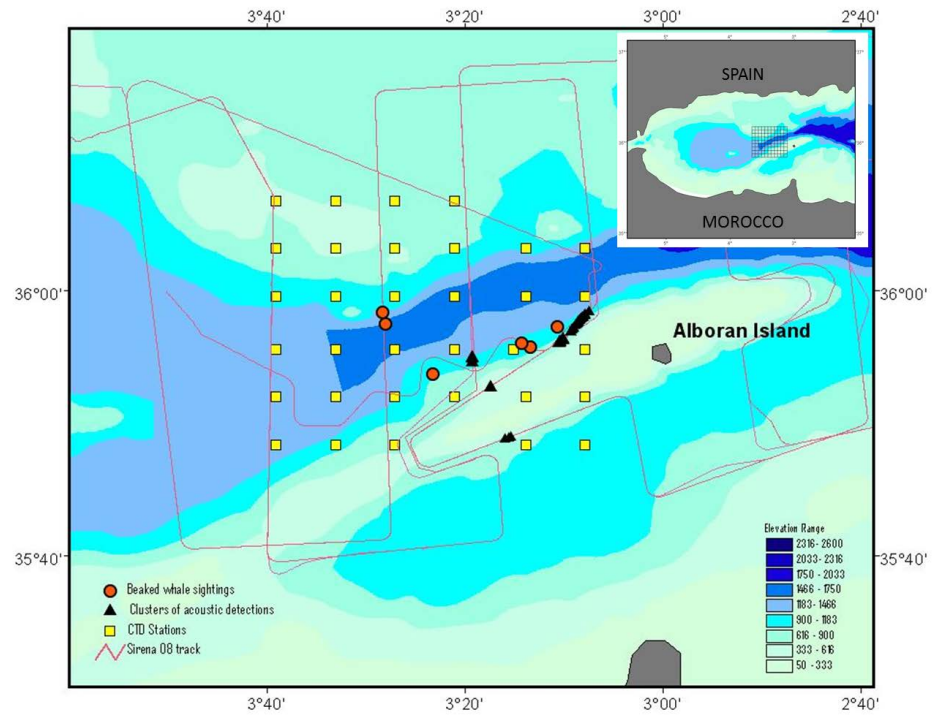
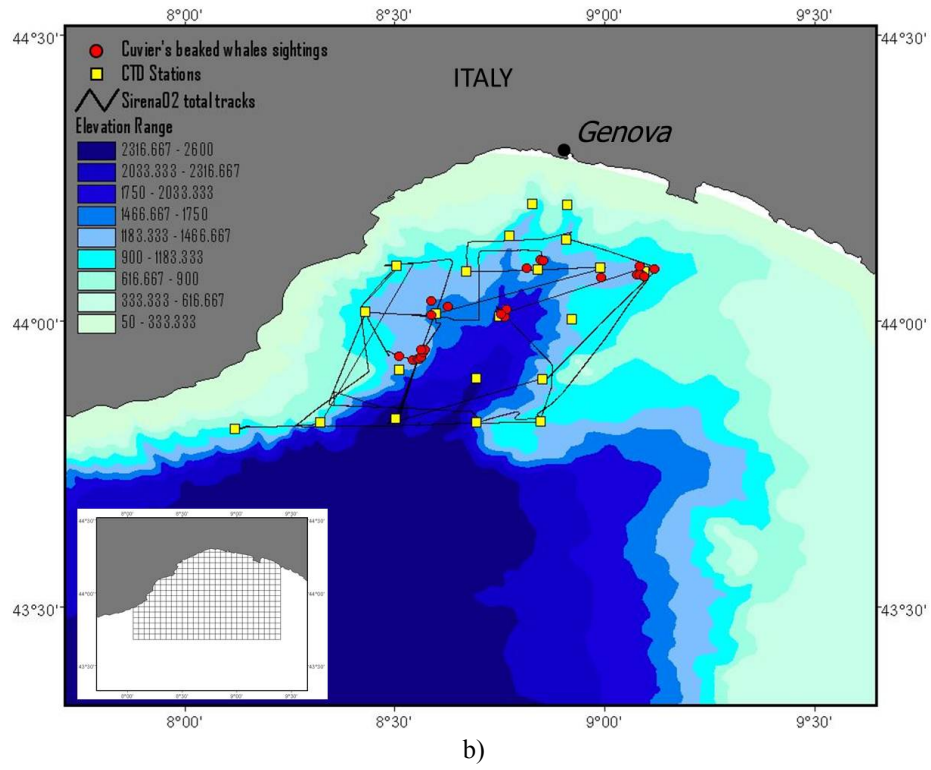


Figure 5. (a) Sirena02 study area in Ligurian Sea (Genoa canyon). (b) Sirena08 study area (Alboran Sea). Beaked whale sightings (red circles) passive acoustic detections (black triangles) and CTD stations (yellow squares) are shown. Ship track lines are also shown.

Water column statistics :

1. Conductivity min value
2. Conductivity max value
3. Conductivity Gradient
4. Temperature min value
5. Temperature max value
6. Temperature Gradient
7. Depth of 13.8 °
8. Fluorescence min value
9. Florescence max value
10. Florescence at the surface
11. Florescence 200 m
12. Depth of the maximum Florescence
13. Florescence Gradient
14. Dissolved Oxygen min value
15. Dissolved Oxygen max value
16. Dissolved Oxygen at the Surface
17. Depth of the maximum Dissolved Oxygen
18. Depth of the minimum Dissolved Oxygen
19. Dissolved Oxygen Up Gradient
20. Dissolved Oxygen Down Gradient
21. Density minimum value
22. Density max value
23. Depth of the maximum Density
24. Density Gradient
25. Salinity minimum value
26. Salinity max value
27. Depth of the maximum Salinity
28. Depth of the minimum Salinity
29. Salinity Gradient
30. Sea Turbidity minimum
31. Sea Turbidity maximum
32. Sea Turbidity mean
33. Sea Turbidity SD
34. Sea Turbidity median
35. Sound Velocity minimum
36. Sound Velocity maximum
37. Depth of the maximum Sound velocity
38. Depth of the minimum Sound velocity
39. Sound Velocity gradient

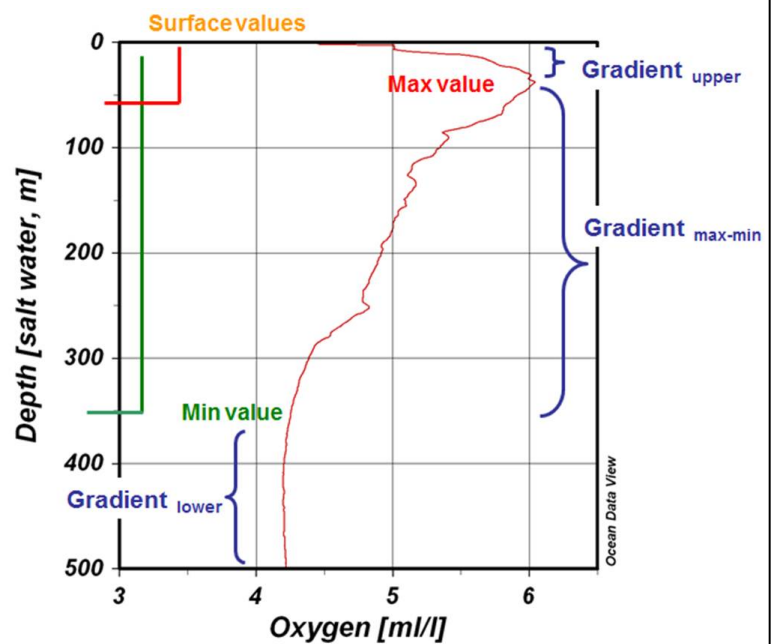


Figure 6. Water column statistics calculated for every oceanographic parameter considered. The deployment of a Conductivity, Temperature, Depth (CTD) Rosette Frame and the plot of an oxygen profile as a function of depth are also shown.

Stepwise Logistic Regression analysis was performed using the water column statistics as covariates. In all the study areas, the species presence was found significantly correlated ($P < 0.05$) with the dissolved oxygen profile features, and, in particular, was correlated with the depth of the maximum value of dissolved oxygen (ml/l, Depth O₂ max). All the models showed a good overall accuracy, the percentage of correct predictions being higher than 70%. However, inverse correlations were outlined for the Alboran Island area and Northwestern Tyrrhenian sea area. On the other hand, a direct correlation was found with maximum dissolved oxygen depth in the Ligurian Sea area (Fig. 7). These

correlations suggest that the depth of the maximum values of dissolved oxygen may be used as a tracer of water masses exchanges. The sign of the correlation (i.e. direct or inverse) could be explained by downwelling or upwelling phenomena. Both the Alboran and Tyrrhenian sea areas are characterized by upwelling phenomena, respectively induced by topography (e.g. a sort of funnel effect induced by the sea bottom which affects the water column profiles in the investigated area in the Alboran sea) and by the dominant wind direction in the Tyrrhenian sea area. On the other hand, the Genoa canyon area is characterized by a topography-induced downwelling of the water masses. These marine environments showing high hydrodynamic activity have apparently a special ecological meaning for beaked whales.

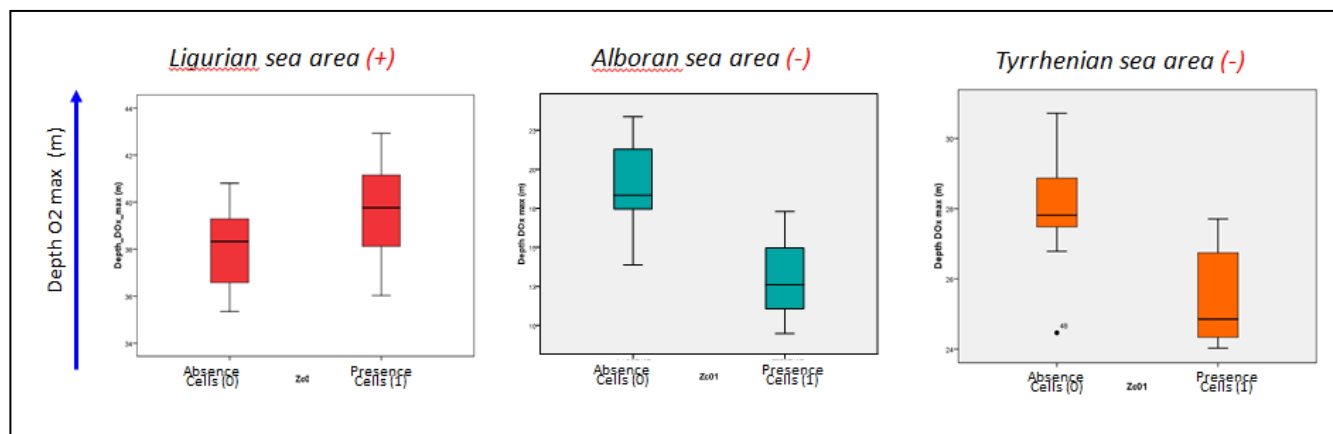


Figure 7. Correlations found between beaked whale presence/ absence cells and depth of O₂ max value in the three study areas.

2. Comparison of the results obtained from acoustic-based and visual-based models.

This second modeling exercise was run for Cuvier's beaked whales (*Ziphius cavirostris*), sperm whales (*Physeter macrocephalus*) and dolphins (genus *Delphinidae*). In this analysis, both visual and acoustic observations, collected during the third leg of the MED-09 research expedition in the Tyrrhenian Sea area, were modeled (Tab.2 and Fig.8-9).

The correlations between cetacean presence/absence and physiographic parameters (i.e depth and slope) were investigated with the aim of comparing the results obtained from acoustic-based and visual-based models. Fin whale (*Balaenoptera physalus*) presence/absence was also modeled using only visual data.

Table 2. Visual and Acoustic database used for the modeling exercises.

Med 09 (leg 3) Data	Beaked whale	Sperm whale	Dolphins	Fin whale
Number of sightings	6	18	57	22
Number of acoustic detections	8	21	58	

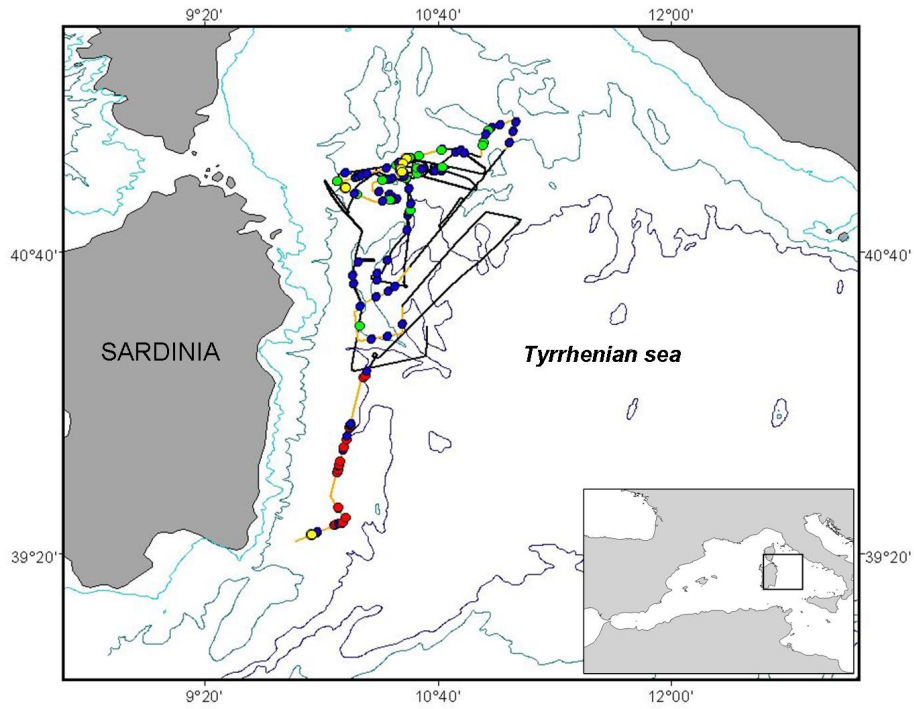


Figure 8. Visual observations. Fin whale (green circles), sperm whale (red circles) Cuvier's beaked whale (yellow circles,) and dolphins (blue circles) sightings are shown. Med-09 cruise tracks are shown, orange lines indicate the positive effort.

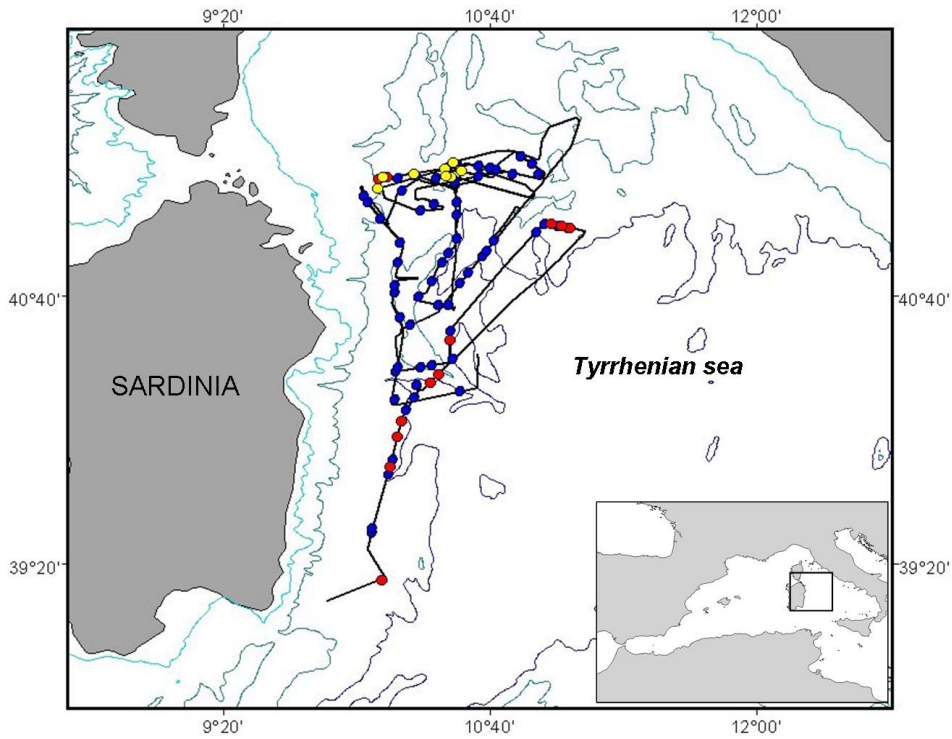


Figure 9. Acoustic detections. Sperm whale (red circles), Cuvier's beaked whale (yellow circles) and dolphins (blue circles) clusters of detections are shown. Med-09 cruise tracks are shown.

A Stepwise logistic regression approach was used to correlate both the visual observations and the acoustic detections with the cell statistics of depth and slope. Significant correlations were outlined ($P < 0.05$) for all the species either using visual or acoustic data. (Tab.3).

The acoustic detection-based model for beaked whales, probably due to the low sample size, was found significant only at a 0.10 level. It is reasonable to expect that increasing the sample size this model becomes fully significant.

Table 3. Visual-based and Acoustic-based model results. Cetacean presence/absence was correlated with depth and slope features (i.e. the cell slope and depth minimum, maximum, SD and mean values).

Visual based models			
<i>Species</i>	<i>predictor</i>	<i>Sig</i>	<i>Overall accuracy</i>
Sperm whale	MEAN Slope	0.009	86,4
	SD Depth	0.000	
Cuvier's beaked whale	MEAN Slope	0.008	89,40%
Dolphins (<i>Delphinidae</i>)	SD Depth	0.007	60.1%
Fin whale	MEAN Slope	0.008	70,30%

Acoustic based models			
<i>Species</i>	<i>predictors</i>	<i>Sig</i>	<i>Overall accuracy</i>
Sperm whale	MEAN Slope	0.035	57.30%
Cuvier's beaked whale	MIN Depth	0.083*	63.2%
Dolphins (<i>Delphinidae</i>)	SD Depth	0.000	54.1%

* Sig. < 0.10

All the models showed a good accuracy, however visual observations-based models had higher percentages of correct overall predictions. This model exercise demonstrates that acoustic data can be used for modeling cetacean presence/absence, although further work should be done to understand how to improve the accuracy of the acoustic-based models.

IMPACT/APPLICATIONS

Understanding the habitat preferences of sensitive species (i.e. marine mammals) is a critical step forward the developing of Risk Assessment tools to support managers and sound-producers in predicting which marine areas deserve a higher protection level. Once determined the key habitat characteristics and developed the tools to estimate the probabilities of high or low density areas, it is possible to manage the estimated risks through proposing mitigations measures. This research contributes in creating the knowledge background about the potential predictors of the sensitive species habitats that are appropriate for different study areas and the modeling approaches that can be used. Both static (i.e. topography features) and dynamic (i.e. CTD parameters) have been proved as valid species presence/absence predictors. Such models may constitute the knowledge basis for sound-producers and managers of the environment for choosing between mitigations alternatives. Models of

this kind may be also employed to predict the sensitivity of a marine area to every new underwater-noise-producing facility such as an offshore wind- or wave- farm. An example of this application was given in Azzellino et al., 2011.

RELATED PROJECTS

The project entiteled “Marine Mammal Risk Mitigation Projects” conducted by NATO Undersea Research Centre (NURC) in La Spezia, Italy (<http://www.nurc.nato.int/research/mmrm.htm>), is closely related to this reasearch. To study the distribution of mammals we are using a multiyear, integrated dataset based on oceanographic, biological, and hydrographic parameters. The analysis dataset included the NURC/MMRM database of marine mammal sightings, oceanographic parameters (CTD, XBT, XCTD), and passive acoustic detections provided by CIBRA, Centro Interdisciplinare di Bioacustica Ricerche Ambientali University of Pavia(<http://www3.unipv.it/cibra/>).

PUBLICATIONS

Azzellino, A., Lanfredi, C., D’Amico, A., Pavan, G. Podesta, M., Haun, J. 2011. Risk mapping for sensitive species to underwater anthropogenic sound emissions: model development and validation in two Mediterranean areas. *Marine Pollution Bulletin*, 63: 56-70.

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